Review on paper manuscript se-2017-5:

Summary:

In this paper and based on earlier findings (Glover, 2009; 2010), the author derives a new theoretical interpretation of the saturation index contained in Archie's second law. The essence of this interpretation is the extension of the "generalized Archie's law" outlined by the author in Glover (2010), where the saturation index is viewed as being "formally the same as the phase exponent, but with respect to a reference subset of phases in a larger n-phase medium".
The author carried out an important task with implications for fundamental rock physics and industrial applications alike. The paper is well structured and, in my perception, mathematically sound and may definitely be suitable for publication in *Solid Earth (SE)*. However, there are a number of substantial issues outlined in the following that I encourage the author to address before the paper can be recommended for publication.

General comments:

1. It should be noted that (1) what is attempted here is a *physical* interpretation of an *empirical* parameter, which I find *per se* problematic. Also, it should be noted that (2) the outlined interpretation comes as an *ad hoc* approach and that (3) no proof is presented that this approach and the resulting interpretation is physically correct. Please comment and clarify within the manuscript.

2. The motivation for performing this particular theoretical investigation is well presented in Section 1. However, this discussion also implicitly suggests that reserves calculations can now be performed with unprecedented precision. There is no proof that this is the case. It should also be noted that there will still be experiments and/or analyses to be performed to parameterize the newly introduced equations. How these experiments/analyses should look like and what type of data is required should be included in the text.

3. The theoretical approach is, mathematically, not very demanding but it appears abstract and hard to grasp. I therefore would wish to see (1) some of the equations to be developed in more detail (e.g. in some appendix), (2) one or more graphical representations of the model to better depict the theory, and, not least, (3) a few example calculations where for some type of rock with some kind(s) of fluid(s) some saturation index is derived and then is compared to existing (experimental) data. Please see also comments below.

Specific comments:

- Section 3; Lines 148-152: I wonder if this is correct. What about percolation or a percolation threshold? Please comment. This comment also applies to Line 260.

- Section 3: In this section a first illustrating sketch should be introduced.

- Section 4; Line 171: Please clarify from where this equation arises.

- Section 4; Lines 178-180: Reasoning unclear. Please improve.

- Section 4; Lines 182-185 and 202: The equations contained here should be fully derived, e.g. within the section or some appendix.

- Section 4; Lines 199 and following: Here, a second illustrating sketch should be introduced.

- Section 4; Lines 213-214: Can this transformation be exemplified or illustrated?

- Section 4; Eq. (10): This equation should be fully derived and also (numerically) exemplified for a 3-phase medium like the one mentioned before in Line 221.

- Section 5: The motivation for this section is somewhat unclear and should be outlined.

- Section 5; Line 234: Please briefly recall the approach of Glover (2009).

- Section 5; Eq. (12), (13), and (14): In my opinion the derivation should be improved/expanded and also inverted such that Eq. (12) is the final outcome (as in Section 6).

- Section 5; Eq. (12): This equation is only correct if one can assume that $n_i \neq f(\Psi_i)$. Please show that this is the case.

- Section 5; Eq. (12): Please show that Eq. (12) yields Eq. (10) or vice versa.

- Section 5; Lines 248-250: To illustrate this statement and by applying either equation I would wish to see an example calculation / numerical evaluation for a 4-phase porous medium (e.g. quarz, clay, water, gas).

Technical corrections:

- the expression “rate of change” suggests some time dependence/derivative and should be replaced throughout the manuscript including in Table 1 by some other, more appropriate, expression

- Lines 51-52: please check if statement is correct

- Glover (2016) not in reference list

- the use of “Φ” (phi) for both porosity and phase volume fractions may lead to confusion. Please reconsider

- Line 125: Equation 4 (?), please check. If correct move Eq. (4) in Line 115 up in text

- Line 131: please check indices in equation

- Line 191: Equation 1 (?), please check

- Line 206: Equation 7 (?), please check

- Lines 237-238: Index “i” missing in “Ψ” (psi).

References:

Glover, P. W. J.: What is the cementation exponent? A new interpretation, The Leading Edge, 82–85, doi: 10.1190/1.3064150, 2009.

Glover, P. W. J.: A generalised Archie's law for n phases, Geophysics, 75 (6), E247-E265, doi: 10.1190/1.3509781, 2010.